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ABSTRACT

A series of experiments, which used the primary memory paradigm of Wickens et al. (1981, 1985) with university students, adults, and 8- and 9-year-old children, found an increase in primary memory capacity with age. Primary memory differs from secondary memory in that the latter is susceptible to proactive interference, whereas the former is not. When the capacity of primary memory is exceeded, some items will be transferred to secondary memory, resulting in proactive interference. In findings obtained by the use of a technique based on these ideas, proactive interference among adults was observed with a set size of six, but not with a set size of four. Among the young children, proactive interference was found with a set size of four but not with a set size of two. Findings suggest that the capacity of primary memory among adults is between four and six items, and among 8- and 9-year-olds, between two and four items. Results also imply that the capacity of primary memory increases with age. (RH)

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Does Active Memory Capacity Change with Age?

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Running head: Active Memory

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Abstract

Primary memory, or information which is currently active, can be distinguished from secondary memory, or information of which we have not been thinking, by the fact that the latter is susceptible to proactive interference, whereas the former is not. The capacity of primary memory can be measured by varying set-size within the primary memory paradigm. When the capacity of primary memory is exceeded, some items will be transferred to secondary memory, resulting in proactive interference. Using this technique, it was found that with adults proactive interference was observed with set-size six, but not with set-size four. With eight-to-nine year olds, proactive interference was found with set-size four but not with set-size two. This suggests that the capacity of primary memory is between four and six items for adults, and between two and four items for eight-to-nine year olds. It also implies that the capacity of primary memory increases with age.

Does Active Memory Capacity Change with Age?

One problem for cognitive development is to measure the capacity of active, or working memory, and thereby decide whether it increases, or remains constant with age. Working memory is often identified with short term memory, and is often measured by some kind of span task. However dual-task studies make it doubtful that short term memory span reflects working memory. It has been shown that the tradeoff between short term memory and (other kinds of) cognitive processing that would be expected under this hypothesis does not occur.

Working memory studies

Insert Figure(s) 1 about here

Figure 1 summarizes relevant experiments by Baddeley & Hitch (1974). Participants are first presented with a preload, consisting of one, two or six digits, then they perform a sentence verification task, after which they recall the digits. In the control condition the verification task was presented first, then the preload was presented and recalled immediately, so the memory load did not have to be carried while performing the verification task. No interference was found between sentence verification and a one- or two-digit memory preload. When the preload was six digits, a small reduction in preload recall was observed, as compared with a control condition. However difficulty of the verification task did not interact with the preload/control manipulation, suggesting that the harder task did not increase demands on short term memory. When participants were

required to continually rehearse the preload, this interaction was observed. Although these experiments lack precision in some respects, they suggest that the processing entailed in a sentence verification task does not automatically displace information stored in short term memory. Further research from the same laboratory (Baddeley, 1981) showed that participants could hold span-sized short term memory loads while performing other cognitive tasks with surprizingly little interference. Baddeley suggested that two systems were involved, a "central executive" and an articulatory loop. This implies that working memory is not a unitary system.

Insert Figure(s) 2 about here

Two experiments by Klapp, Marshburn and Lester (1983) are summarized in figure 2. The memory preload was letters, and the main task was verification of numerical relationships in experiment 1, or a modified Sternberg memory scanning task in experiment 2. In the delay-before-task condition, a five second delay was inserted before the primary task, to permit consolidation of the preload. In this condition, there was no interference between memory load and performance on the verification task. Interference did occur if the verification followed directly on preload presentation, with a corresponding delay afterwards to control retention intervals.

These experiments seem to show that mere retention of a short term memory load does not interfere with a verification task. If verification follows directly on preload presentation, cognitive processes associated with encoding and consolidation of the

preload items apparently interfered with verification. However if these processes were complete before verification, no interference occurred, even though the preload items had to be retained. This suggests that verification does not actually displace items from short term memory. Results consistent with this hypothesis were obtained in an experiment by

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Insert Figure(s) 3 about here

Halford, Bain and Maybery (1984), summarized in figure 3. Digits were presented continuously, at a rate of two per second, starting before each problem, and continuing throughout it. The problems were N-term series reasoning, in either an easy form, which required no premise integration, or a hard form, which required premise integration. In the easy problems, each premise can be checked independently against the target (e.g. P precedes C can be checked against PC in the target, etc.), whereas in the hard problems the first two premises must be integrated and checked to see if they are consistent with the third premise (in the example, P precedes C must be integrated with C precedes X, and the resulting series PCX must be checked against the third premise, P follows X. It is inconsistent in the example shown, so the correct response would be "false"). There is evidence that premise integration imposes a higher processing load than other aspects of N-term series reasoning (Maybery, Bain & Halford, 1986).

An audio probe was presented at one of the four positions shown, and participants were told that when the probe occurred, they should remember as many as possible of the six preceding digits for later recall. If the probe occurred before the

problem (probe 1), digits could be encoded and stored before the problem began, as in the delay-before-task condition of Klapp et al (1983). If however the probe occurred .5 sec after problem presentation, participants would have to encode the digits while performing the problem. With probe 3, encoding would have to begin immediately after response to the problem, and with probe 4, 6-8 sec after problem completion. The timing of the recall prompt was adjusted so the total retention interval was constant.

Comparison of recall scores for probe 1 and probe 4 assesses displacement of information from STM due to N-term series reasoning. There was a small displacement (< 1 item), but it was no larger for the hard than for the easy reasoning task. However there was a considerable reduction in recall if the memory items were encoded while reasoning, and this effect *was* greater for the hard reasoning task. The implication is that reasoning interferes with encoding a memory load, but it is doubtful whether it interferes with mere retention of a short term memory load.

It appears that information can be held for short periods in memory systems (an audio-articulatory system, or a visuo-spatial system), that are independent of major cognitive processes. Interference arises because of mnemonic processes such as encoding, rehearsal, or retrieval, but not because of retention per se. Total processing space is therefore not simply the sum of processing or operating space and short term storage space, because the latter two are not completely interchangeable, there being more than one system involved.

A more important implication however is that we cannot use span tasks to measure the capacity of working memory, not even when the span tasks also involve processing, as in some "working memory" measures. Span performance partly reflects storage in memory systems that are independent of central processing mechanisms. Therefore we need an alternative measure of active memory.

Primary memory studies

Wickens, Moody and Dow (1981) and Wickens, Moody and Vidulich (1985) have shown that primary memory, defined by William James (1890) as information that has not been lost to consciousness, can be operationally distinguished from secondary memory, which consists of information of which we are not currently thinking. This can be done using a rather complex paradigm based on a combination of Sternberg memory scanning, and the Brown-Peterson paradigm, with Wickens' release from proactive paradigm added. The paradigm is summarized in Figure 4. Full details of the experiments are given elsewhere (Halford, Maybery and Bain, in press).

Insert Figure(s) 4 about here

In the primary memory condition, a memory set is presented followed by a probe, participants having to indicate whether the probe was in the memory set. There is no intervening activity, so it is expected that the memory set information will remain active in primary memory.

In the secondary memory condition, the procedure is the same except that a distracting task intervenes between memory set presentation and probe. This activity should displace the memory set items from primary into secondary memory. The primary-secondary memory manipulation produced three effects:

(1) the intercept of the memory scanning function was approximately 100 msec greater in the secondary memory condition, reflecting time to retrieve information from secondary memory,

(2) negative probes produced longer RTs than positive probes for secondary memory, reflecting the lower utility of negative probes as retrieval cues,

(3) proactive interference was observed in secondary but not in primary memory, which Wickens et al interpret as being due to retrieval.

Proactive interference was assessed by using three successive trials in the same semantic category, followed by a shift to a new category. The difference in RT between the first and third trial in a category is a measure of proactive interference.

It should be possible to use this paradigm to measure the capacity of primary, or active, memory. If set-size is greater than the capacity of primary memory, at least some items will have to be offloaded into secondary memory. If we use Wickens et al.'s primary memory procedure, the findings characteristic of secondary memory, should occur with larger set-sizes. In particular, proactive interference should be observed with large but not with small set-sizes.

Accordingly we used Wickens et al.'s primary memory paradigm with set-sizes of 4 and 10 (Wickens et al. had used a maximum of 4), with university student participants. The results are shown in Figure 5. Proactive interference was observed at set-size 10, but not at set-size 4, in both errors and latencies.

Insert Figure(s) 5 about here

In our second experiment we used set sizes 4, 6, 8, and 10, and the results are shown in Figure 6. Proactive interference was found at all set-sizes above four. This suggests that the capacity of primary memory in adults is 4 or 5 items.

Insert Figure(s) 6 about here

We then tested 8-9 year old children on set-sizes 2 and 4. As figure 7 shows, there was proactive interference at set-size four, but not at set-size two. Note that PI has never been observed in the primary memory condition at set-size four with adults, either by us or by Wickens et al. It is clear therefore that the capacity of primary memory is less for 8-9 year olds than for adults. The data also indicate that primary memory capacity of this age group is 2 or 3 items.

Insert Figure(s) 7 about here

This research opens up a new technique for investigating the capacity of primary memory, in adults and children. The technique could be used with children as young as three years, if graphic stimuli were substituted for the words used here. While the task might not have the economy of span tests, it is probably more directly related to active memory. It could also be used to validate other tests of working memory capacity.

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Wickens, D.D., Moody, M.J., & Vidulich, M. (1985). Retrieval time as a function of memory set size, type of probes, and interference in recognition memory. *Journal of Experimental Psychology, 11*, 154-164.

Figure captions

Figure 1. The working memory paradign used by Baddeley and Hitch (1974).

Figure 2. Basic paradigm used by Klapp, Marshburn and Lester (1983), experiments 6 & 7.

Figure 3. Paradigm used by Halford, Bain and Maybery (1984).

Figure 4. Paradigm used by Wickens et al. (1981, 1985).

Figure 5. Interaction of set-size and proactive interference in Experiment 1. Latencies (Figure 5A) and number correct (Figure 5B).

Figure 6. Interaction of set-size and proactive interference in Experiment 2.

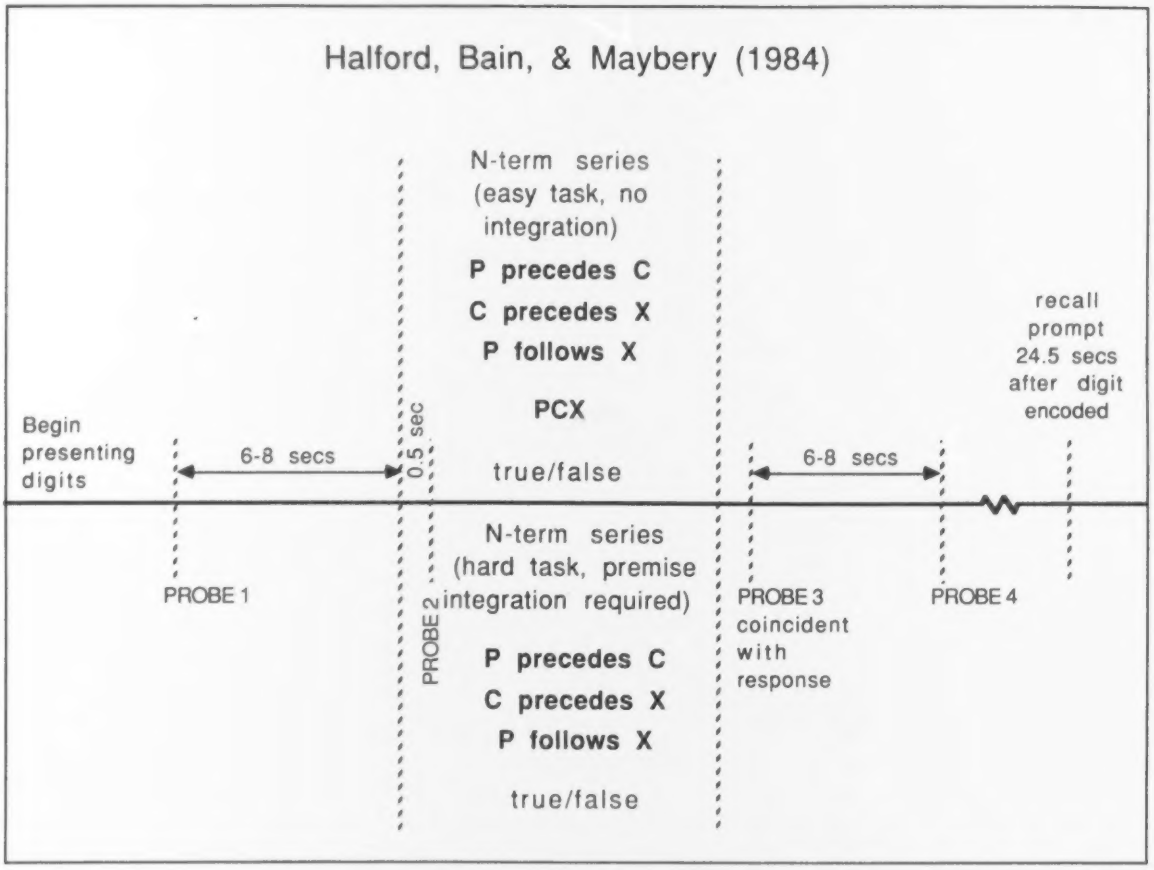
Figure 7. Interaction of set-size and proactive interference in 8-9 year olds in Experiment 3.

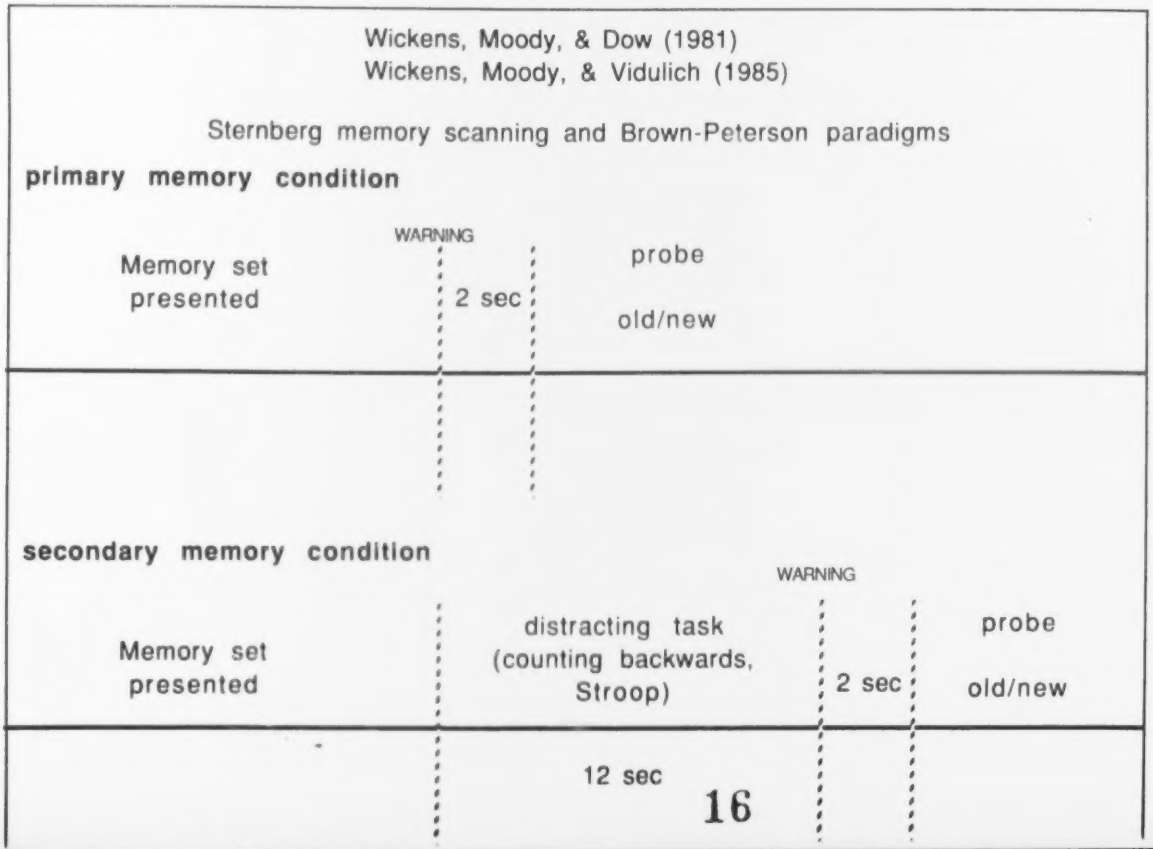
Baddeley & Hitch (1974) Exps. 1,2, & 3.

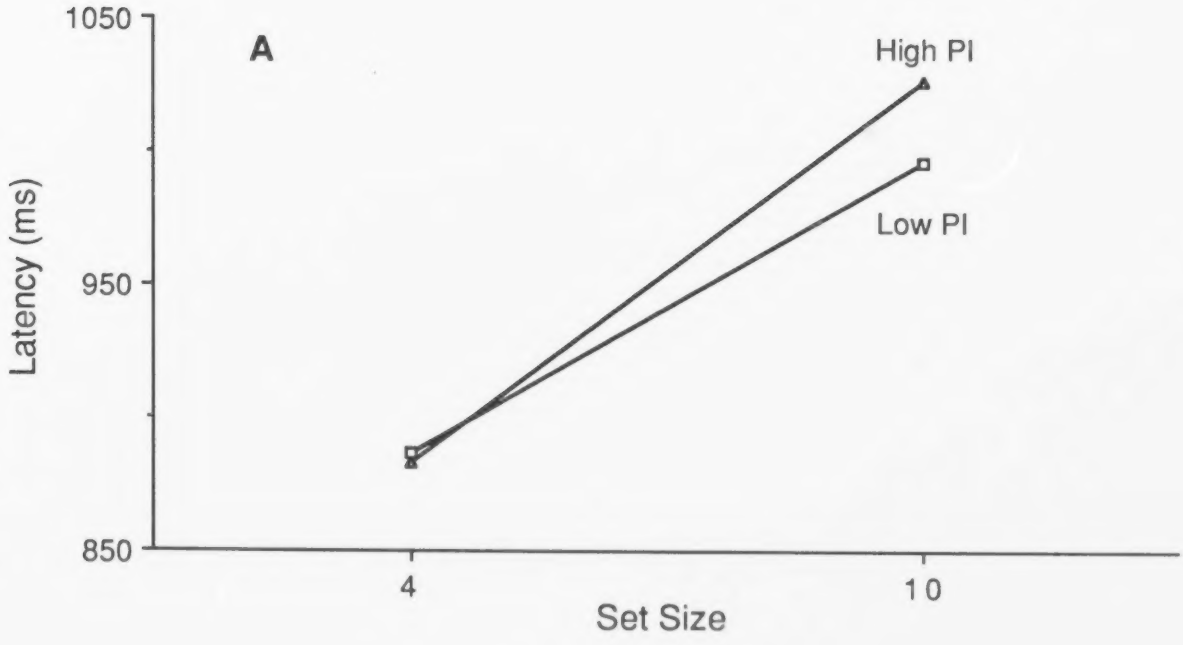
memory preload presentation (digits)	sentence verification	recall digits
In the "concurrent" memory load condition the digits were rehearsed throughout the sentence verification task	A precedes B A B (easy) A is not preceded by B A B (hard)	

Klapp, Marshburn, & Lester (1983), Exps. 6 & 7.

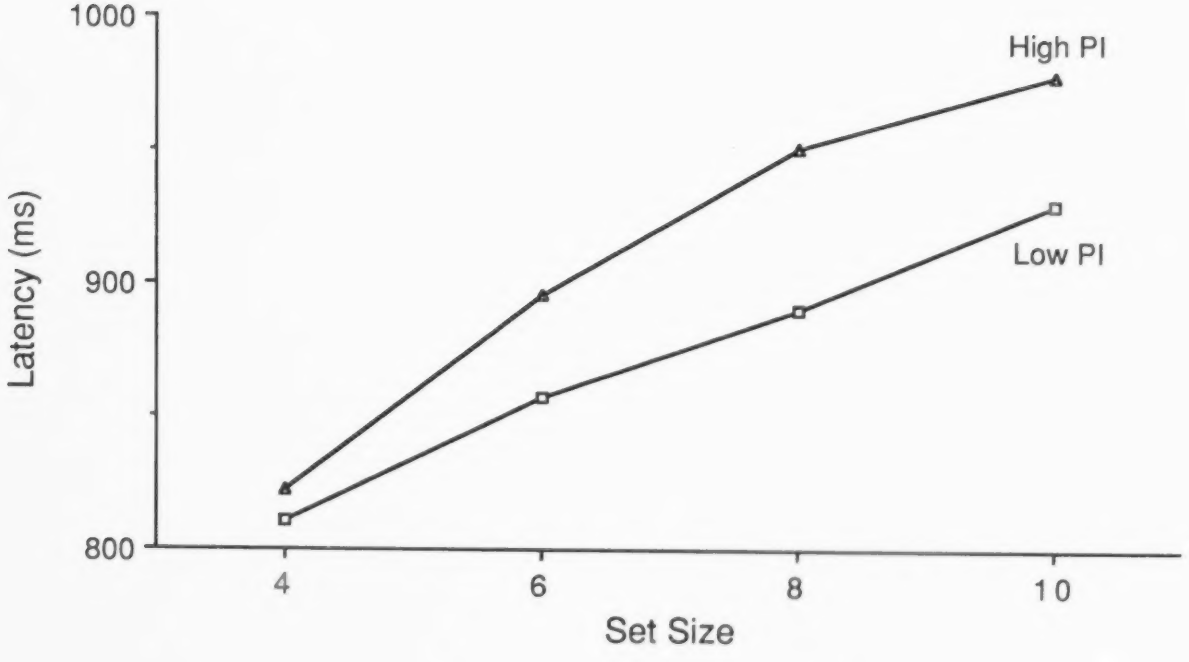
GET READY	250 msec	memory preload presentation, 3,6, or 9 letters (successively)	5 sec consolidation delay (delay before task condition only)	STOP REHEARSAL 500 msec	1 sec delay	Verification task "5 > 7" true/false	5 sec delay (delay after task condition only)	recall prompt
						modified Sternberg memory scanning task		

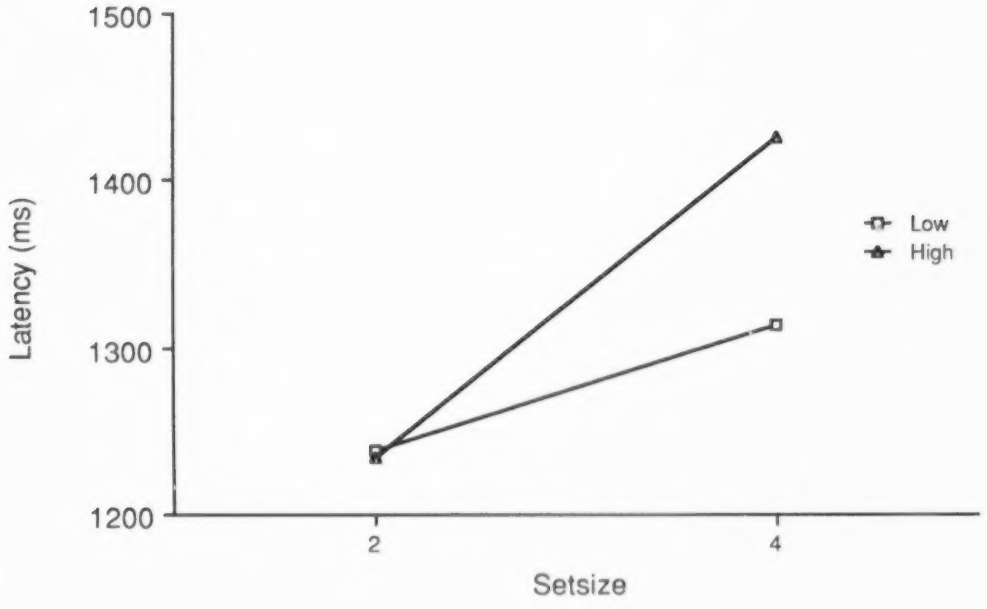

Halford, Bain, & Maybery (1984)
N-term series
(easy task, no
integration)
P precedes C
C precedes X
P follows X
PCX
true/false
recall
prompt
24.5 secs
after digit
encoded
Begin
presenting
digits
6-8 secs
0.5 sec
6-8 secs
PROBE 1
PROBE 2
N-term series
(hard task, premise
integration required)
P precedes C
C precedes X
P follows X
true/false
PROBE 3
coincident
with
response
PROBE 4


Wickens, Moody, & Dow (1981)
Wickens, Moody, & Vidulich (1985)
Sternberg memory scanning and Brown-Peterson paradigms
primary memory condition
WARNING
Memory set
presented
2 sec
probe
old/new
secondary memory condition
WARNING
Memory set
presented
distracting task
(counting backwards,
Stroop)
2 sec
probe
old/new
12 sec


A
1050
950
850
Latency (ms)
High PI
Low PI
4
10
Set Size

B
10.0
9.5
9.0
8.5
8.0
Number correct
Low PI
High PI
4
10
Setsize


1000
900
800
Latency (ms)
High PI
Low PI
4
6
8
10
Set Size


1500
1400
1300
1200
Latency (ms)
2
4
Setsize
Low
High